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The purpose of the present study was to examine the distribution of subcutaneous fat and to derive several equations to predict body density (BD) using an amplitude modulation type of ultrasonoscope (A-mode ultrasonoscope, FUKUDA FT-100). Subjects were 188 male physical education major college students ranging in age from 18 to 24 years. Fifty subjects who were randomly selected out of the 188 subjects were measured for BD by the underwater weighing technique and were used to derive the equation for estimating the BD.

Four points (scapular, triceps, suprailliac, and thigh) of subcutaneous fat which had been commonly selected, height, and weight were measured. The four measurements of fat for the 188 subjects indicated rather small means and small standard deviations respectively. Furthermore, histograms of those measurements tended to show a significant skewness for low values and deviated from the normal probability curve (p<0.01). Regarding the means, they were almost all the same except for suprailliac measurements. Suprailliac measurements showed more large values and were distributed rather more widely than the other measurements.

Derivations of the multiple regression equations from anthropometric measurements were made using the Wherry-Doolittle test selection method (Clarke & Clarke, 1972). Four measurements (triceps, suprailliac, height, and weight) were selected by the Wherry-Doolittle method. The multiple regression equation based on these four measurements was as follows:

\[ BD = 1.03894 - 0.005411(X_1) - 0.000891(X_2) + 0.000506(X_3) - 0.000353(X_4) \]  \( \text{R} = 0.660, \text{SEE} = 0.00603 \)

where BD: body density (g/cm³), X₁: triceps(mm), X₂: suprailliac(mm), X₃: height(cm), X₄: weight(kg), R: multiple correlation coefficient, and SEE: standard error of estimation. On the other hand, a more simple equation based on only fat measurements was as follows:

\[ BD = 1.10907 - 0.004085(X_1) - 0.001295(X_2) \]  \( \text{R} = 0.631, \text{SEE} = 0.00624 \)

Correlation coefficients of these formulas were not sufficiently high and SEE's of the formulas were not so small. It was shown that derivation of equation to predict BD with high accuracy was not easy when physical education major students were selected as subjects. However, considering the homogeneous nature of the subjects examined in the present study, the present formula could be expected to be applicable when used with groups with similar characteristics.

Key words: Fat thickness, Ultrasonoscope, Body composition

Many investigators have addressed themselves to the task of developing a simplified and widely applicable method for accurately assessing body density (BD) and percentage of body fat (%fat) in human subjects. These measurements can be estimated precisely by several laboratory tests such as radiography, total body water, total body potassium, and underwater weighing technique. However, these tests require complex procedures and elaborate techniques or devices. Therefore, though
accuracy of estimation decreases, more simple methods have been desired when the application is made to many people within a brief time as in cases such as screening tests or field tests.

The most common of these simple methods is to use formulas derived from anthropometric measurements such as diameters, circumference, width, or skinfold measurements (Key & Brożek, 1953, Wilmore & Behnke, 1968, 1969, Pollock et al., 1979). In Japan, the formula based on only skinfold measurements (triceps and scapular, Nagamine & Suzuki, 1964) have been most commonly used. In general, skinfold measurements have been frequently used for the index of fat. However, these methods have less reproducibility and some other problems (Toyokawa et al., 1984a, b). For example, measurement cannot be applied to obese men, because skinfold calipers have a limitation for the fat thickness to fold. Furthermore, skinfold calipers are difficult to fold skin of thigh or calf.

Recently, new devices called ultrasonoscopes which make use of ultrasonic waves have been applied for measuring subcutaneous fat. These devices are compact and not so expensive, and the above limitations for obese men or the specific sites are improved. Furthermore, special knowledge or technique are not needed for testers and the application is more comfortable for subjects than that of skinfold caliper. Therefore, it could be expected to spread to screening tests or field tests. However, these ultrasonoscopes have not come into wide usage and the equation for predicting BD using the measurements of the ultrasonoscopes also has not been fully developed.

The purpose of the present study was to examine the distribution of subcutaneous fat and to derive several equations to predict BD using an amplitude modulation (A-mode) ultrasonoscope. There have been a few studies to examine the distribution of subcutaneous fat among children and the infant population (Toyokawa, 1986, 1987a, b). However, the other populations have not been fully studied. In the present study, physical education major college students were selected as subjects.

**METHODS**

1. **Subjects**

Subjects were 188 male physical education major college students ranging in age from 18 to 24 years. They had performed about 1 hour of physical training, which included jogging, sprinting, and weight training, 5 days per week. Fifty subjects who were randomly selected out of the 188 subjects were measured for BD and were used to derive the equation for estimating the BD.

2. **Procedures**

1) Measurement of subcutaneous fat

Subcutaneous fat was determined by using an amplitude modulation type ultrasonoscope (A-mode ultrasonoscope, FUKUDA, FT-100). This ultrasonoscope was composed of a probe which detects a target wave and a main body which has a tube for displaying the wave. It was already ascertained that the target wave reflects from the interface between subcutaneous fat layer and muscles (Toyokawa et al., 1984a, b). The ultrasonoscope was set to 5MHz for ultrasonic waves and could be determined to the nearest 0.1mm for measuring subcutaneous fat.

Four points (indicated as follows) of subcutaneous fat which had been commonly selected, hegiht, and weight were measured. The anatomical landmarks for the selected sites were as those used by Wilmore and Behnke (1969).

a) Scapular: Inferior angle of the scapular.
b) Triceps: Midway between the acromion and olecranon processes on the posterior aspect of the arm, the arm held horizontally.
c) Suprailiac: On the crest of the ilium at the midaxillary line.
d) Thigh: On the anterior aspect of the thigh midway between the hip and knee joint.

Height and weight were measured with the subject standing to the nearest 1mm and 0.05kg respec-
tively.

2) Determination of body density

Body density was obtained for each subject by the underwater weighing technique. The procedures were almost the same as in the previous report (Nigorikawa & Oishi, 1988). The underwater weighnings were conducted in a circular tank (120cm in diameter, 150cm in height). Underwater weight of each subject was derived by means of a load cell (KYOWA, LU-10KE) connected by a steel wire to a metal cradle. The transducer output was amplified by a strain amplifier (KYOWA, DPM-602B) and recorded on a penoscilloscope. A minimum of ten consecutive determinations was performed for one subject. The selection of the representative underwater weight was made according to the method of Wilmore and Behnke (1969).

Residual lung volume (RV) was determined out of the water by the closed circuit, helium dilution method modified from Meneely et al. (1960). Although RV and underwater weighing determinations were administered separately, the same postural positions (sitting) were used for both (Pollock et al., 1976). A minimum of two determinations were made on each subject.

Considering the gastrointestinal gas, a volume of 100ml was added to RV when calculating the BD (Buskirk, 1961). The revised formula of Brožek et al. (1963) was used to compute %fat from the BD.

3. Derivation of multiple regression equation

Derivations of the multiple regression equations from anthropometric measurements were made using Wherry-Doolittle test selection method (Clarke & Clarke, 1972). This method allows selecting of the variables in order of their importance. Multiple correlation coefficients are computed cumulatively after each variable is added to the equation. After the multiple correlation is completed, the process may be continued to compute a multiple regression equation.

RESULTS

1. Distribution of subcutaneous fat

In order to examine the distribution of subcutaneous fat for the physical education major college students, 4 sites for 188 subjects were measured. Figure 1 shows histograms of the four measurements of subcutaneous fat by means of ultrasonoscope. The means and SDs of the four measurements of fat for the 188 subjects were as follows: scapular; 4.64mm±1.06mm, triceps; 4.11mm±0.71mm, suprailliac; 5.81mm±2.30mm, thigh; 4.18mm±0.76mm, respectively. Regarding the means, they were almost all the same except for suprailliac measurements. Suprailliac measurement showed more large values and were distributed rather more widely than the other measurements. Furthermore, histograms of four measurements all tended to show a significant skewness for low values and deviated from the normal probability curve (p<0.01).

2. Relationship between physical characteristics and body density

Table 1 shows the means and SDs of the measurements and the correlation coefficients (r) between the BD and the other measurements for 50 subjects.

![Fig. 1](image-url) Histograms of the four measurements of subcutaneous fat by means of A-mode ultrasonoscope. A: scapular, B: triceps, C: suprailliac, D: thigh. See details in text.
Table 1  Means (M) and standard deviations (SD) of the measurements and the correlation coefficients (r) between body density (BD) and other measurements.

<table>
<thead>
<tr>
<th></th>
<th>r</th>
<th>M</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>BD (g/cm³)</td>
<td>-</td>
<td>1.08515</td>
<td>0.00805</td>
</tr>
<tr>
<td>Age (yrs)</td>
<td>-0.154</td>
<td>21.0</td>
<td>2.1</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>0.210</td>
<td>172.2</td>
<td>5.2</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>-0.218</td>
<td>63.0</td>
<td>6.7</td>
</tr>
<tr>
<td>Triceps (mm)</td>
<td>-0.538**</td>
<td>4.16</td>
<td>0.81</td>
</tr>
<tr>
<td>Scapular (mm)</td>
<td>-0.511**</td>
<td>4.72</td>
<td>1.13</td>
</tr>
<tr>
<td>Suprailliac (mm)</td>
<td>-0.510**</td>
<td>5.35</td>
<td>2.30</td>
</tr>
<tr>
<td>Thigh (mm)</td>
<td>-0.376**</td>
<td>4.18</td>
<td>0.75</td>
</tr>
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</table>

**p<0.01

Each subcutaneous fat measurement showed a significant correlation coefficient to the BD (P<0.01). Especially, triceps showed the highest value of correlation coefficient. Namely, triceps measurement showed the highest relation to the BD. In contrast, other variables (i.e., height, and weight) indicated no significant relation to BD.

3. Prediction of body density

A selection of items and derivations of the multiple regression equations was made using the Wherry-Doolittle test selection method as described above. These procedures were applied to 50 subjects. At first intercorrelations of seven measurements and the BD were calculated. The criterion was the BD, and the mean and SD of BD for 50 subjects were 1.08515g/cm³ and 0.00805g/cm³ respectively.

Four measurements (triceps, suprailliac, height, and weight) were selected by Wherry-Doolittle method. Namely, two ultrasonoscope measurements were selected out of the four measurements. The multiple regression equation based on these four measurements was as follows:

\[
BD = 1.03894 - 0.005411(X1) - 0.000891(X2) + 0.000506(X3) - 0.000353(X4) \quad \text{Formula(1)}
\]

\[
\text{R=0.660, SEE=0.00603}
\]

where BD: body density (g/cm³), X1: triceps(mm), X2: suprailliac(mm), X3: height(cm), X4: weight(kg), R: multiple correlation coefficient, and SEE: standard error of estimation.

On the other hand, a more simple equation based on only fat measurements was as follows:

\[
BD = 1.110907 - 0.004085(X1) - 0.001295(X2)
\]

\[
\text{R=0.631, SEE=0.00624}
\]

**DISCUSSION**

Determination of human body fat has been an object of interest in the fields of medicine or physical education etc. Especially, knowledge of quantity of body fat would be useful to help prevent some geriatric diseases or to help in weight control for athletes. Skinfold measurement obtained by using skinfold caliper has been one of the major sources of information of body fat. However, skinfold calipers have been pointed out to possess many problems in measuring subcutaneous fat. At first, skinfold calipers have some technical problems in application to subjects. Though there is a standard for the skinfold pressure, various factors such as finger pressure or the way of pinching interfere with the measurement. The second one is based on methodology. Namely, skinfold calipers measure the skin thickness at a situation of double layer, and this situation induces several errors of measurement (Toyokawa, 1983). From the consideration of the above problems, a new method for assessing the body fat using ultrasonic waves has been given attention.

Recently, the new devices called ultrasonoscopes which make use of ultrasonic wave have been used for measuring subcutaneous fat. The first application of these devices to a living body was in an investigation of Dussik (1950). Some studies which investigated the accuracy, reliability, or sensibility of the ultrasonoscopes have already been presented (Bullen et al., 1965, Borkan et al., 1982, Sanchez & Jacobson, 1978). In summary of these results, though a slight difference was shown among the measurements which were obtained by different testers, the accuracy, reliability, and sensibility were sufficient-
ly high when using ultrasonoscopes rather than skinfold calipers. Namely, it can be interpreted the ultrasonoscopes can be applied practically in assessing body fat with sufficient validity. Therefore, the application of these devices for screening tests or field tests should be considered.

There have been a few studies using ultrasonoscopes to examine the distribution of subcutaneous fat of human. The major subjects for there studies were infants or children (Toyokawa et al., 1984a, b). Though data for general adults have also been reported (Saiki & Toyokawa, 1987), the number of subjects studied has not been sufficient and other populations have not been fully studied. In the present study, physical education major college students were selected as subjects. As a result, four ultrasonoscope measurements for 188 subjects in the present study were distributed within a narrow range. Furthermore, histograms of these measurements tended to show a significant skewness for low values and deviated from the normal probability curve. From the consideration of the mean values, the values were almost all the same except for suprailiac measurements. Suprailiac measurement indicated more large values and were distributed rather more widely than the other measurements. However, all of these values were remarkably small compared with the data of Saiki & Toyokawa (1987). Anyway, as there are not enough data for normal male adults, further discussion could not be given. Therefore, more data for normal male adults would be needed as a control.

The equation for predicting the BD using ultrasonoscope has not been fully studied. In general, the relation between the measurements obtained by use of skinfold caliper and ultrasonoscope is used for predicting the BD. Namely, ultrasonoscope measurements which were multiplied by coefficients obtained from the above relation were substituted for equations based on skinfold terms, which have been commonly used (personal communication). However, as this method contains fundamental problems as a matter of course, accuracy of predicting BD was decreased further. Therefore, developing equations to estimate BD using ultrasonoscope measurements directly have been desired.

The mean and SD of BD for 50 subjects examined in the present study were 1.08515g/cm² and 0.00805g/cm² respectively. These values can be calculated to 7.0% and 3.1% fat respectively, using the formula of Brożek et al. Considering the average value of Japanese male young adults (13.0% fat, Kitagawa, 1984), our subjects were rather lean. Therefore, care should be taken to apply our formulas to men in general.

One of the purposes of the present study was to derive several regression equations based on ultrasonoscope measurements to estimate BD. As shown in the results, multiple correlation coefficients (R) were 0.660 and 0.631 respectively. Correlation coefficients of these formulas were not sufficiently high and SEE of the formulas were not so small. It was shown that derivation of an equation to predict BD with high accuracy was not easy when physical education major students were selected as subjects. However, considering the homogeneous nature of the subjects examined in the present study, these values could be accepted in applying the formula when the application is limited to groups with similar characteristics.

REFERENCES
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